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Renewable energy integration into community energy systems: A case study of new urban residential development

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ABSTRACT

During the recent past, the individual responsibility of climate change mitigation has been acknowledged by the society at large. Energy planning is pivotal in mitigating GHG emissions and adopting climate resilient strategies. However, community level energy planning has been overlooked in the urban development planning and the approval process. Many energy and emission reduction approaches are still voluntary for the developers and been pursued on ad-hoc basis.

The objective of this study is to propose a systematic framework for renewable energy integration in community development. A scenario-based study was conducted for an upcoming neighbourhood in Okanagan, British Columbia (BC), Canada. Scenarios were assessed based on the life cycle cost (LCC) and GHG emission reduction. The scenarios were then compared based on costs and benefits to key stakeholders. Results of this study revealed that a higher share of renewable sources in the energy mix does not necessarily reduce LCC or GHG emissions. The benefits which can be achieved via incorporating renewables to the regional energy mix varies, depending on the existing energy sources in the mix. Therefore, regional power grid mix influences the feasibility and acceptability of RE integration at a given location. Developers should be aware of the optimal investment level which could be fully or partially recovered by premium home prices. The government should promote this practice via various incentives such as tax credits, grants etc. Findings of this research would mainly inform urban developers in renewable energy planning and local government in formulating climate action policies.

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1. Introduction

Atmospheric greenhouse gas (GHG) concentrations have been doubled in the past century due to the anthropogenic emissions. It is widely accepted that this rapid increase is the main reason for the climate change. Energy is a critical resource in ensuring the functioning of a modern society (Suganthi and Samuel, 2012). In Canada, energy use (i.e. stationary combustion sources, transport and fugitive sources) accounts for 81% of the GHG inventory (Environment Canada, 2014a). Fossil fuels are the primary energy source for socio economic energy demands (Edenhofer et al., 2012). Hence, reduction of energy consumption and replacement of conventional fossil fuel based energy sources with renewable energy sources (RES) are foundational for reducing GHG emissions and other related environmental impacts (Denis and Parker, 2009).

United Nations Paris Agreement in 2016 was a historic agreement among 195 countries to combat climate change. One of the major agreements reached through this venture was to make an effort in restricting the global temperature rise to 1.5 °C above pre-industrial levels (United Nations Framework Convention on Climate Change, 2016). This target requires strengthening of mitigation plans more than ever in the history. Presently climate change initiatives can be observed at the global level (e.g. Kyoto protocol), country level (e.g. Federal Sustainable Development Strategy Canada), provincial level (e.g. British Columbia climate action charter) and municipal level (Environment Canada, 2014b; Ministry of Environment BC, 2010).

The present-day world is made out of a giant network of interconnected communities. Hence, a global movement towards

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Nomenclature

Acronyms

BC	British Columbia
GHG	Greenhouse Gas
LCC	Life cycle cost
LCA	Life cycle analysis
MSW	Municipal solid waste
NG	Natural Gas
PV	Photovoltaics
RE	Renewable energy
RES	Renewable Energy Sources
SCC	Senior congregate care
SFA	Single-family attached
SFD	Single-family detached
UND	Urban Neighbourhood Development

Abbreviations

WtE	Waste-to-Energy
CA$	Canadian dollars
USD	United States dollars
O&M	Operations and maintenance
HH	Household
$kgCO_2e$	kilogrammes of Carbon Dioxide equivalent
sq.ft.	Square feet

Units of measurement

kW	Kilowatt
GJ	Gigajoule
kWh	Kilowatt-hour
MWh	Megawatt-hour
a	per annum
pc	per capita
kWh/kWp/a	Kilowatt-hours per kilowatt peak per annum
TCO_2e/a	Tonnes of Carbon Dioxide equivalent per annum

sustainability can be initiated through communities (Roseland, 2012). Since urban communities will be the home for 70% of the global population by 2050, climate conscious community level initiatives are vital for achieving ongoing climate action targets (WHO, 2014). Energy sustainable communities are those which use Renewable Energy Sources (RES) and act in energy efficient ways (Schweizer-Ries, 2008). A sustainable urban energy system can be established considering three initiatives, namely energy efficiency; energy conservation; and by switching to RES (Denis and Parker, 2009). The interest towards RES is principally due to the adverse effect of fossil fuels towards the ecosystems and climate (Edenhofer et al., 2012). Furthermore, humanity is concerned over the possibility of fossil fuel running out (Boyle, 2004). The global demand in clean energy technologies has continued to rise for the last decade. In fact, globally $367 billion was invested in renewable energies in 2015 (Clean Energy Canada, 2016).

1.1. Energy planning for communities

Over the years, on-site renewable electricity generation has become an important consideration in urban neighbourhood development (UND) (Maier and Gemenetzi, 2014). A comprehensive literature review showed that many of the research studies associated with renewable energy selection have primarily focused on the national level (e.g. Indonesia (Tasri and Susilawati, 2014); Jordon (Jaber et al., 2008); North Korea (Yi et al., 2011); Greece (Diakoulaki and Karangelis, 2007); and Austria (Madlener et al., 2007)). Comparatively, fewer studies have focused on the micro-generation strategy and selecting renewable energy sources at the local level (e.g. Istanbul (Kaya and Kahraman, 2010); Belgrade (Jovanović et al., 2009)).

Renewable energy use and the associated GHG emissions reduction have been the focus of a wide body of research. The studies conducted by Morales and Sauer (Morales and Sauer, 2001) (Ecuador), (Kadian et al., 2007). (India), (Manzini et al., 2001). (Mexico) all indicate that the use of RE and substitution of conventional energy sources can lead to significant reductions in GHG emissions. However, carbon emissions reduction through RE use leads to inevitable economic “mitigation costs”, as indicated by Islas et al. (2004). In this study, the authors maintain that research and development with regards to RE technologies are essential for acceptable future GHG mitigations costs.

The energy and emission plans will provide a holistic overview of the policies and plans adopted for achieving sustainability goals (Ishii et al., 2010). Energy and emission planning is prevalent in municipalities in Canada (ICLEI, 2014). Energy planning for climate conscious neighbourhoods results in mutual benefits to developers and residents. Currently, the construction industry and urban planners are collaborating to support transition into low-carbon communities (Gansmo, 2012). Analysis of carbon footprint has become one of most critical feature in urban planning (Engel et al., 2012). Renewable energy planning at community level focuses on distributed generation which matches supply from locally available energy resources supply with demand (Denis and Parker, 2009). This approach ensures that the energy system has more congruence with the local needs and opportunities, and provides a chance for stakeholders at the community level in getting involved in the planning (Denis and Parker, 2009).

However, community energy planning in Canada is more focused on energy efficiency improvements and conservation, and only limited consideration is given to renewable energy integration in UND (Denis and Parker, 2009). Possible reasons for this lack of interest could be the relatively higher costs, need for technical expertise, and other complexities associated with RE planning. In order to select the most applicable technologies and implement them at community level, communities require consultation with outside expertise, and localised management of environmental and health impacts (Denis and Parker, 2009; Pape-salmon et al., 2003). UND projects are often constrained by limited budgets of small communities and municipalities. In fact the main obstacle associated with use of renewable energy at this level is the high initial investment requirement (Koirala et al., 2016). However, overcoming these barriers and developing localised energy systems can ensure long-term energy independence and energy security in communities (Rae and Bradley, 2012).

Development of renewable-based energy systems is expected to deliver benefits to communities in terms of energy costs, environmental impacts, and social factors. Effective planning and decision making plays a key role in maximising the above mentioned benefits. Previous studies have investigated multiple approaches in energy planning. Long range energy simulation is used to track the impacts of energy use and emissions over long-term (Kadian et al., 2007; Shrestha and Rajbhandari, 2010). LEAP software is a commonly used tool for long range energy analysis, incorporating

growth factors to planning (Kadian et al., 2007; El-Fadel et al., 2001). Carbon pinch analysis is used to plan for an optimised energy mix with minimised carbon emissions (Tan and Foo, 2007). Mathematical optimization techniques are used in defining the best mix and sizing for energy systems under multiple selection criteria (Alsayed et al., 2014). In scenario-based studies, a limited number of alternative scenarios are defined by the decision makers (Thompson and Duggirala, 2009), out of which the best scenario is selected based on a number of factors such as economic and environmental impacts (Petrillo et al., 2016). Scenario-based studies has been frequently used in energy-related research (Islas et al., 2003; El-Fadel et al., 2001; Ghanadan and Koomey, 2005; Cai et al., 2008). While energy planning can thus be considered as a problem of academic interest, devising practical methods to plan and evaluate energy systems is a necessity for higher RE penetration in community energy systems. Decision makers and developers need to be provided with tools which help them in defining the best RE alternatives for a particular community, without the need for extensive technical expertise.

Energy demand in Canada can be categorized into five sectors, i.e., residential, commercial and institutional, industrial, transportation, and agriculture (Natural Resources Canada, 2013). Subsequent end energy use differs according to the energy demand sectors. This energy demand is catered through primary and secondary energy sources. Residential energy use in Canada is among the highest in the world (Environment Canada, 2014c). Due to its vast land area and geographic location, Canada's climate is highly variable and extreme, affecting secondary energy uses in residential units (i.e. mainly energy demand for winter heating and summer cooling) (Environment Canada, 2014c). The residential sector has special significance in the overall energy use in Canada, accounting for 17% of the energy use within the country as well as 15% of the GHG emissions (Natural Resources Canada, 2015). Canadian residential energy demand is expected to reach 1635 PJ in 2040. National Energy Board estimates that energy use in the residential sector will increase at an average annual rate of 0.3% (National Energy Board of Canada (2016)). The main factors influencing residential energy consumption may include type of dwelling, heated area and number of persons in the household (Statistics Canada, 2013). Other factors that influence the residential energy consumption include outside temperature (number of heating and cooling days), home characteristics (i.e. insulation, fenestration and building envelope), living habits (frequency of the air conditioner use, temperature set point, frequency of the washer and dryer use), number of occupants, age of the house and equipment (i.e. construction year, age of the air conditioner, age of the washing machine) and energy efficiency of the electrical appliances (Statistics Canada, 2013; Eleftheriadis and Anagnostopoulou, 2015).

Energy sources used in residential sector vary extensively across Canada (NRCan, 2015). Factors accounting for the difference in energy mix between different regions are varying energy prices, energy demand for end uses and locational availability of fuel types. For example, Atlantic Canada uses electricity, biomass and natural gas to meet residential energy demand. Provinces such as BC, Manitoba and Quebec use electricity for residential energy demand due to the availability of clean and low-cost hydroelectricity, whereas Alberta and Saskatchewan are heavily reliant on natural gas (National Energy Board, 2013). In order to estimate the exact costs and benefits of replacing the existing energy sources with RES, it is necessary to consider the energy mix at a regional level.

Energy planning is a multi-stakeholder problem. At a community level, the participation of various interest groups such as local governments and other decision makers, community developers, construction industry, as well as residents is important (Polatidis and Haralambapoulos, 2004). Stakeholder acceptance ensures the success of any RE integration initiatives (Eleftheriadis and Anagnostopoulou, 2015). Hence, it is necessary to evaluate and address the impacts and concerns relevant to different stakeholder groups at the planning stage (Polatidis and Haralambapoulos, 2004). In the matter of community development, the allocation of economic costs and benefits, and facility management responsibilities are of particular interest to the stakeholder groups.

This research analyzes the feasibility of renewable energy integration in community energy planning. A scenario-based long-term energy study is conducted for a proposed residential neighbourhood in BC, Canada. By analysing a select number of scenarios for the proposed community, the economic and environmental impacts for the community and the various stakeholders are identified. The outcomes are expected to help community developers define practical methods to use RE effectively in community energy systems. The lessons learnt from this can be used to provide recommendations for improved energy planning practices and policies.

2. Methodology

This study mainly focuses on operational energy demand at the community level and the related environmental impact (i.e. GHG emissions). In the analysis, only the residential component of community energy consumption was considered. This is defined as the energy consumed by the occupants within the residential units of the community. Generally, community energy plans are framed for 20–50 years (Stockholm Environmental Institute, 2014). Therefore, 25-year period was considered for this study.

The proposed upcoming urban neighbourhood is located in Okanagan (British Columbia, Canada). The data provided below on residential units was extracted from the community development plan of the above mentioned neighbourhood, after consultation with the developers. Reasonable assumptions were made where ever data was not available. The composition of the community at the end of the development phase is as follows. The total population of the community is 6500. Once the community is fully developed, there will be 2125 single-family attached (SFA) units, 40 single-family detached (SFD) units, and 725 senior congregate care (SCC) units.

The energy demand and supply overview for the community was developed based on the information obtained from Natural Resources Canada and other sources (Maruejols et al., 2011). Fig. 1 illustrates the energy uses and potential supply sources for the community. The options outlined were used in identifying and selecting RES to replace the conventional fuels in community energy generation.

The energy consumption data for the proposed residences as estimated based on the data for BC in 2011 (Statistics Canada, 2011), and the average area of a dwelling are given in Table 1. (The square footage information for dwellings were obtained through consultation with FortisBC.)

While a number of factors such as climate conditions and construction methods may influence energy consumption within a residential unit, only the macro-level energy use variation between different dwelling types was considered in this analysis. The objective of this study is to investigate the possibility of catering the energy demand of a community through RES, and to define practical methods for developers to select RE alternatives. Therefore, a detailed analysis of the micro-level impacts of climatic and design related factors was considered to be beyond its scope.

A systematic framework was developed for comparing alternative renewable energy plans for neighbourhood planning. Fig. 2 illustrates the methodology adopted for comparing renewable energy alternatives in this study, and assessing the impacts and

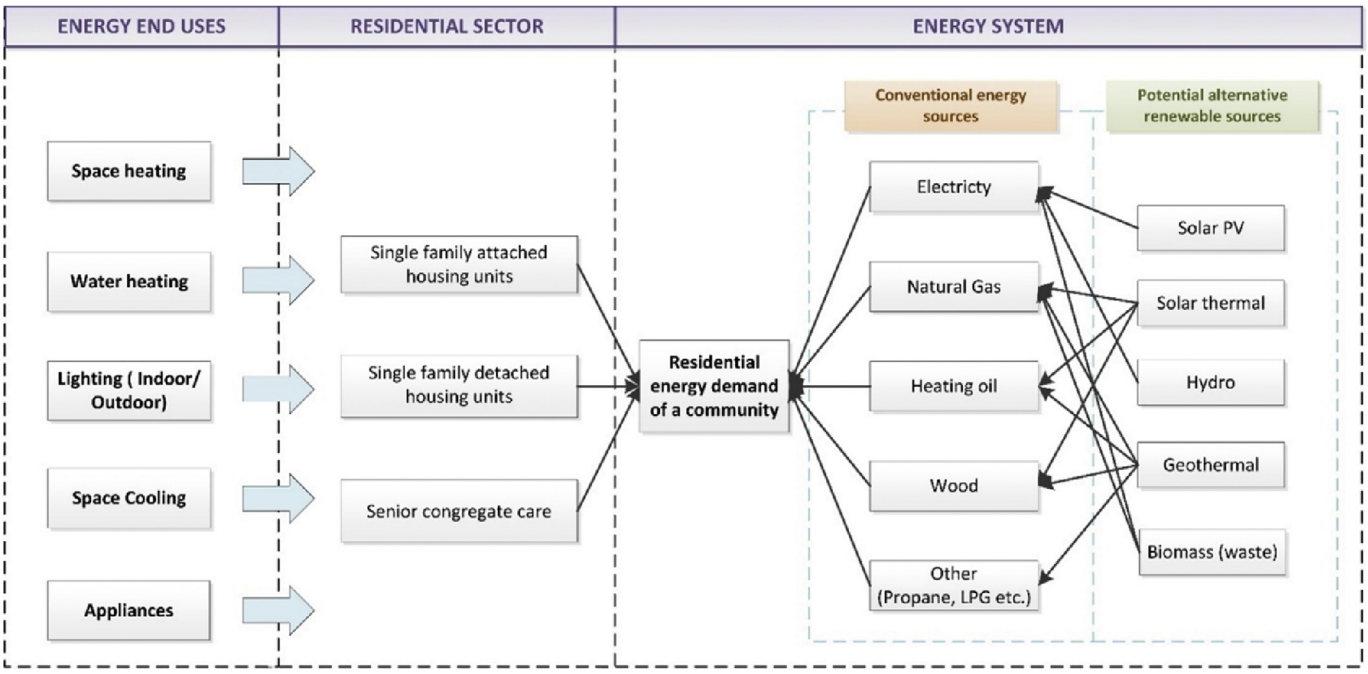

Fig. 1. Energy demand and supply overview for residential sector.

Table 1
Energy intensity by dwelling type.

Dwelling type	Annual energy consumption per household (GJ)	Household area (sq. ft.)
Single-family attached	76	2259
Single-family detached	125	1988
Apartments	46	1094

benefits on the community in order to select the best option for the community. Initially, the available RE technologies were identified based on the information obtained through literature and expert opinion. This was followed by a screening process to select the most suitable technologies in the local context. The approach adopted in this study was to develop scenarios based on the selected technologies and the community energy requirements. The developed scenarios were evaluated and compared on the basis of energy, economics and environment. The impacts to multiple stakeholders were assessed. This strategy was used in selecting the most suitable scenario for practical implementation from the developed options.

Four energy management scenarios were defined considering the energy demand and the potential use of renewable energy. The scenario details are provided in the case study section. Information obtained from literature was used in defining the scenarios, which were further verified through expert consultation.

In the analysis, the electricity generated by the centralised plants (solar PV and municipal solid waste) were allocated to the households on the basis of the relative size of each unit, characterised by the floor area (San Francisco's Department of the Environment, 2013). The same approach was adopted in allocating the life cycle costs of the centralised plants to households, when evaluating the economic impacts at the occupant level. Under the net metering programme, BC Hydro pays 9.99 ¢/kWh, for any excess electricity provided through a renewable source. (Hydro, 2016a). The economic returns on any excess credit on renewable electricity were assessed using this rate.

Following assumptions were considered in conducting the energy analysis.

a. Building configuration is similar for all households within a single dwelling type ("cookie-cutter homes").
b. Seniors congregate care type dwellings were approximated to be similar to multifamily apartments, based on the information provided in the community development plan.
c. Annual energy demand intensity by each dwelling type will be as depicted in Table 1 for the entire duration of the study.
d. Furthermore, it is assumed that the energy end uses depicted in Fig. 1 apply to all the residences for the entire duration of the study. The main end energy uses for the residential sector and their percentage contributions to energy demand were identified as following based on data published by the Government of Canada; space heating (61.7%), water heating (20.3%), appliances (12.6%), lighting (3.7%) and space cooling (1.7%) (Government of Canada (2013)). The above percentage contributions are assumed to remain uniform for all dwelling types.
e. Only the energy sources mentioned under the scenarios presented in Table 2 will be used in supplying the energy needs of the community. All houses belonging to a single dwelling types are assumed to have similar energy use patterns.
f. The community development is assumed to be completed overnight, with full community occupancy commencing from 2016. The cost analysis will consider a lifetime of 25 years for the constructed energy facilities.
g. Salvage values at the end of life are assumed to be zero for all technologies.

2.1. Energy system scenarios

The four scenarios developed for the case study analysis are detailed in Table 2. Each scenario has a different energy mix for supplying the electricity and heating needs of the community. In the first scenario, where a business-as-usual approach is taken, BC grid electricity and natural gas are used to supply the electricity and heating needs respectively. FortisBC data indicates that using natural gas for heating purposes can lead to significant cost savings

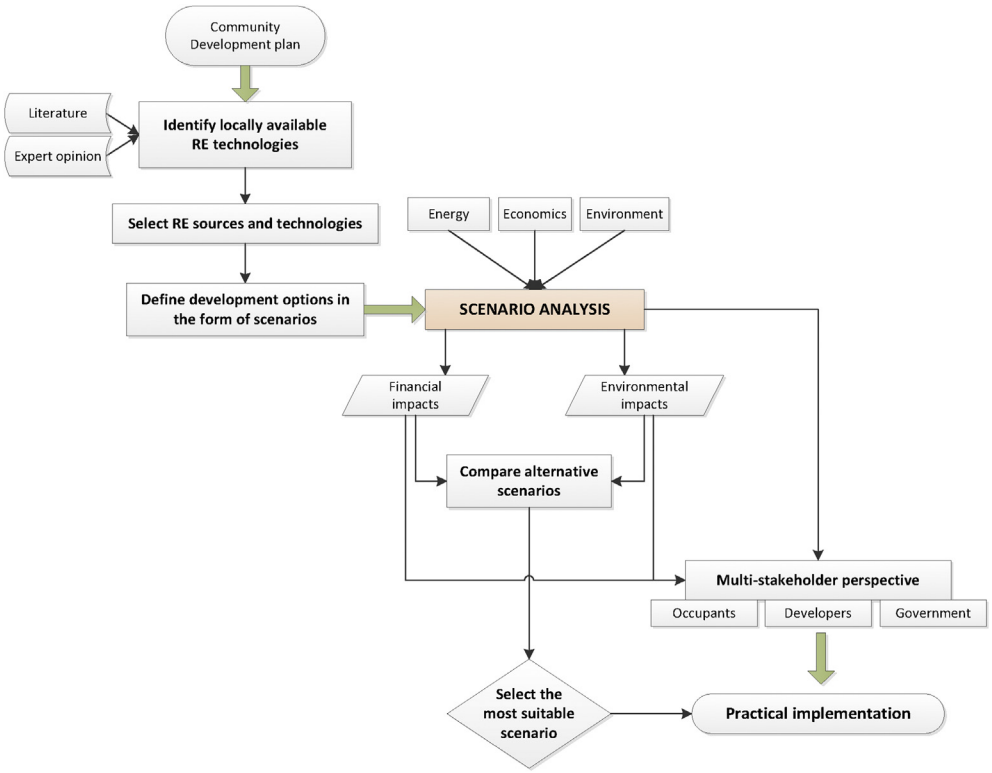

Fig. 2. Scenario-based analysis and selection research methodology.

Table 2
Energy system scenarios developed for the community.

Scenario		Energy supply	
		Electricity	Heating
Scenario 1 – *Business-as-usual*	Renewable	–	–
	Non-Renewable	BC grid electricity	Natural gas
Scenario 2 – *Solar PV*	Renewable	1. Centralised 2 MW solar PV plant 2. Rooftop solar PV systems at household level *System capacities* SFA – 2 kW SFD – 4 kW SCC – None	–
	Non-Renewable	Remaining electricity needs supplied through BC grid	Remaining heating energy needs supplied through natural gas
Scenario 3 – *Solar PV & geothermal heating*	Renewable	1. Centralised 2 MW solar PV plant 2. Rooftop solar PV systems at household level *System capacities* SFA – 2 kW SFD – 4 kW SCC – None	1. Geothermal heating at household level through an Earth Energy System (EES) designed to provide 60% of the household heating load[a]
	Non-Renewable	Remaining electricity needs supplied through BC grid	Remaining heating energy needs supplied through natural gas
Scenario 4 – *Solar PV & geothermal heating with waste-to-energy*	Renewable	1. Centralised 2 MW solar PV plant 2. Rooftop solar PV systems at household level *System capacities* SFA – 2 kW SFD – 4 kW SCC – None 3. Centralised 300 kW waste-to-energy (WtE) incineration plant generating electricity using municipal solid waste (MSW)	1. Geothermal heating at household level through an Earth Energy System (EES) designed to provide 60% of the household heating load
	Non-Renewable	Remaining electricity needs supplied through BC grid	Remaining heating energy needs supplied through natural gas

[a] Natural Resources Canada recommends EES systems to be sized to provide 60%–70% of the demand load (for both water and space heating) for maximum cost effectiveness (FortisBC, 2016c).

Table 3
Distribution of energy use business-as-usual scenario.

Fuel sources			GJ supplied from fuel/HH/a		
End use	Fuel	% of households	SFA	SFD	SCC
Space heating	Natural gas	100%	47.88	78.75	28.98
Domestic water heating	Natural gas	100%	12.92	21.25	7.82
Residential appliances	Electricity	100%	10.64	17.5	6.44
Lighting and space cooling	Electricity	100%	3.8	6.25	2.3

Table 4
Costing data for RE systems.

System		Capital	O&M	Capacity	Generation output	Total	
						Capital	O&M
Rooftop PV	Cost	5066 (National Renewable Energy Laboratory, 2016)	27.3 (National Renewable Energy Laboratory, 2016)	Varies by HH type		5066	27.3
	Units	CA$/kW	CA$/kW/a			CA$/kW/HH/a	CA$/kW/HH/a
Centralised PV	Cost	2633 (National Renewable Energy Laboratory, 2016)	21 (National Renewable Energy Laboratory, 2016)	2000	2039.4	5,265,000	41600
	Units	CA$/kW	CA$/kW/a	kWp	MWh/a	CA$	CA$/a
Geothermal	Cost	25000 (Canadian GeoExchange Coalition, 2016)	142 (National Renewable Energy Laboratory, 2016)	Varies by HH type		25000	142
	Units	CA$/HH	CA$/HH/a			CA$/HH	CA$/HH/a
MSW	Cost	1148 (Hydro, 2013b)	75 (Hydro, 2013b)	300	0.3678	4574206	46
	Units	CA$/T	CA$/T	kW	MWh/pc/a	CA$	CA$/pc/a

(FortisBC, 2016a). Therefore, space and water heating will be supplied 100% through natural gas, while appliances, lighting and space cooling are powered 100% through grid electricity.[1] In the next three scenarios, the RE share in the mix is gradually increased through solar PV and biomass electricity, and geothermal heating for the residences.

Based on the annual energy intensities for the three dwelling types as listed in Table 1, the energy use for each end use was calculated for each type under the business-as-usual scenario. This information is provided in Table 3. This information was used in combination with the RE supply information from the cases outlined in Table 2 in defining the community energy mix under each scenario.

2.1.1. Additional assumptions and information used in the analysis

Data obtained through literature was used in estimating the energy generation potential of each renewable source. The solar PV systems installed at household level on the rooftops of detached housing are assumed to be south facing and tilted, with no impact from shading, with an approximate annual generation of 1200 kWh of electricity per kW of installed capacity (Hydro, 2016b). The PV systems are grid connected, and the household solar energy generation is subject to net metering. A solar regional factor of 1133 kWh/kWp/a is taken for the analysis for Kelowna region (BC HydroFortisBC, 2015), along with an inverter efficiency of 90% for the PV system (Fletcher, 2014).

The following equation (Equation (1)) is used in calculating the annual energy output of a solar PV system (Vanek and Albright, 2008).

$$E = C \times RF \times \eta_{inv} \quad (1)$$

- E = Annual energy output
- C = System capacity
- RF = Annual solar regional factor (solar potential)
- η_{inv} = Inverter efficiency

The per capita MSW generation potential is taken as 0.613 tonnes per annum according to the BC average values (Recycling Council of British Columbia (RCBC), 2006; Hydro, 2013a). A conversion factor of 0.6 MWh/tonne is assumed for the MSW incineration plant (Hydro, 2013b).

2.1.2. Technical and financial factors of renewable energy options

Following technical and financial information obtained from the literature and given under Table 4 was used for energy and economic analysis. The financial data in Table 4 is presented in Canadian dollars (CA$).[2] The assumptions and relationships presented in Section 2.1.1 were used in the energy generation and cost calculations.

Technical and financial factors associated with the renewable energy technologies are presented in detail under Appendix A. The costs associated with centralised plants were allocated to the households on the basis of square footage for each household.

2.1.3. Energy cost data

The electricity and natural gas rates are provided as per FortisBC data. Table 5 summarises the annual energy costs for electricity and natural gas, if the entire residential energy demand were fulfilled through those sources (scenario 1). The current energy rates used by FortisBC (given in Appendix B) were used in calculating the below costs. The equations used in calculating the electricity and natural gas costs per household are provided under Appendix B.

[1] As a newly planned and developed community, it is assumed that all residences would be supplied with a similar energy system.

[2] The cost data adapted from U.S sources were converted at a currency rate of 1 USD = 1.3 CA$.

Table 5
Annual energy cost for electricity and natural gas.

Dwelling type	Energy consumption		Electricity Cost per billing cycle	Annual cost	
				Electricity	NG
	GJ/a	kWh/a	CA$/HH/cycle	CA$/HH/a	CA$/HH/a
Single-family attached	76	21111.11	473.00	2877.42	604.07
Single-family detached	125	34722.22	813.05	4946.04	901.99
Senior congregate care	46	12777.78	264.81	1610.92	421.67

3. Results

The findings of the study are presented below, under the themes of energy, emissions and economics.

3.1. Energy and emission analysis

The energy analysis has been conducted for the scenario of a fully developed neighbourhood, based on the assumptions listed in Section 2.1. Under the developed scenarios, the energy consumption and costs were calculated at household level and community level.

3.1.1. Energy supply and demand

In the scenario analysis, it is assumed that centralised and distributed solar PV systems, and biomass plant would cater the electricity needs, while geothermal systems would partly replace the natural gas heating. The information provided on household energy intensities and end uses in Tables 1 and 3 were used in calculating the energy requirements for heating and electric applications in a household. This information was extrapolated to community level, based on the information given in the community development plan. The energy supply available from each RES was calculated based on scenarios defined in Table 2. Any remaining energy needs which cannot be catered by RES are supplied through conventional sources. The supply sources and their contribution under each scenario are detailed in Table 6.

Fig. 3 illustrates the share supplied by conventional and renewable sources in each scenario. Approximately two thirds of the community's energy demand would be supplied through renewable sources in scenario 4.

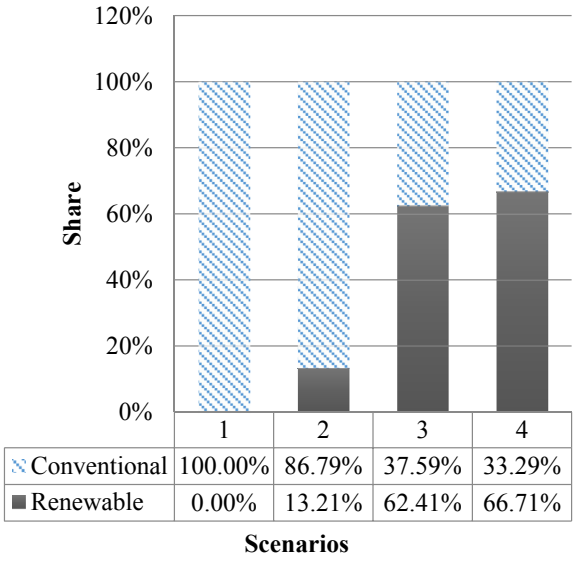

Fig. 3. Share of fuel sources by scenario.

3.1.2. Household level energy supply

The energy supplied by the distributed RE technologies (rooftop PV and geothermal heating) in each residence was added to the renewable energy supplied by the centralised plants (allocated to each dwelling type on the basis of square footage) to estimate the net contribution by RE sources at household level. Per household

Table 6
Energy supply at community level.

Dwelling type			Single-family attached units (SFA)	Single-family detached (SFD)	Seniors congregate care (SCC)	Total
Scenario 01						
Total energy use (GJ/a)	Heat	Natural Gas	132430	4100	27347	163877
	Electricity	Electricity	29070	900	6003	35973
Scenario 02						
RE supply (GJ/a)	Heat	N/A	0	0	0	0
	Electricity	Rooftop PV	18360	691	0	19051
		Centralised PV	7342			
Conventional supply (GJ/a)	Heat	Natural Gas	132430	4100	27347	163877
	Electricity	Electricity	9580			
Scenario 03						
RE supply (GJ/a)	Heat	Geothermal	79458	2460	16408	98326
	Electricity	Rooftop PV	18360	691	0	19051
		Centralised PV	7342			
Conventional supply (GJ/a)	Heat	Natural Gas	52972	1640	10939	65551
	Electricity	Electricity	9580			
Scenario 04						
RE supply (GJ/a)	Heat	Geothermal	79458	2460	16408	98326
	Electricity	Rooftop PV	18360	691	0	19051
		Centralised PV	7342			
		MSW plant	8607			
Conventional supply (GJ/a)	Heat	Natural Gas	52972	1640	10939	65551
	Electricity	Electricity	973			

Table 7
Household energy supply by source.

Scenario	SFA (GJ/HH/a)		SFD (GJ/HH/a)		SCC (GJ/HH/a)	
	Renewable	Conventional	Renewable	Conventional	Renewable	Conventional
1	0	76	0	125	0	46
2	11	65	21	104	2	44
3	49	27	82	43	24	22
4	52	24	86	39	26	20

energy supply data for each scenario are provided in Table 7. Based on the information provided in Table 2, the annual energy supply availably from each energy source was calculated.

3.1.3. Annual emissions forecast

Fig. 4 illustrates the expected annual emissions for the entire community under each proposed scenario. The average emissions factors for the energy sources was used in calculating the total emissions, based on the energy supply mix in each scenario. (The emissions factors for different energy sources are given in Appendix C.) It can be noted that overall community emissions reduce from scenario 1 to 3, while the greatest reduction is achieved through the installation of geothermal heating system at household level. In the final scenario, the emissions have slightly increased, possibly due to the use of MSW as a source for generating electricity. Appendix D provides further information on the breakdown of emissions in each scenario by energy source.

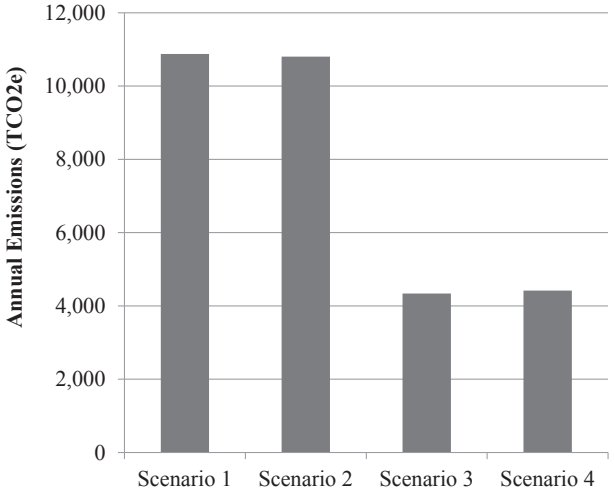

Fig. 4. Community annual emissions forecast by scenario.

3.2. Economic analysis

The costs of RE alternatives were analysed on a household basis as well as at the community level, in order to find the economic impacts to the occupants and the community as a whole.

3.2.1. Costs at household level

The capital costs and O&M costs of household level interventions (i.e. rooftop PV and geothermal heating systems) were allocated to each household, based on the available cost data. The capital costs were annualised over the 25-year life span. The annualised LCC of the centralised solar PV and MSW plants (over 25 years) were allocated to the households on the basis of square footage. The discount rate for the period is taken as 3% .[3] The costing data provided under Table 4 were used in the LCC calculation for RE systems.

Table 8 provides the details on the annual recurring energy costs in the form of energy bills and O&M costs for each scenario. The following equation (Equation (2)) was used in calculating recurring energy costs at household level.

$$\begin{aligned}&\textit{Annual recurring energy cost per HH}\\&= \textit{Annual O\&M costs for household level RE installations}\\&\quad + \textit{Annual per household allocation of O\&M costs for centralised plants}\\&\quad + \textit{Annual grid electricity and natural gas energy bill}\end{aligned} \tag{2}$$

Fig. 5 depicts the variation in annual recurring costs (consisting of the sum of energy bills and the O&M costs for the RE options) for each scenario. This summarises the annual economic effects due to the scenarios for a household of each dwelling type. The recurring energy costs include the energy bills, and O&M costs for the RE installations. It is evident that at household level, the annual recurring costs generally reduce with the increase in energy share produced through RE sources. While this pattern can be clearly identified for single-family attached and detached households, the effect is less beneficial for the senior congregate care apartments. One reason behind this observation is the lack of roof installed PV for such apartments. Additionally, the lower energy consumption of these dwellings make the incurring of allocated O&M costs for centralised plants uneconomical.

3.2.2. Costs at community level

Fig. 6 presents the variation of total annual energy related costs and annual emissions for the entire community. The annual energy cost of the community was estimated considering annualised LCC of the renewable energy systems installed at distributed and centralised levels, and the energy bills incurred for the use of natural gas and grid electricity. As expected, the annualised energy cost of the community increases with a higher share of renewables in the energy mix. However, the emissions increase slightly from scenario 3 to 4, as described previously, possibly due to the inclusion of biomass based electricity.

The annualised energy cost was compared with the total community level emissions to study the overall effect of each scenario, and to compare the actual costs incurred with the emissions. The following equation (Equation (3)) represents the annualised energy costs at community level.

$$\begin{aligned}&\textit{Annualised energy cost at community level}\\&= \textit{Annualised LCC of RE installations}\\&\quad + \textit{Annual energy bills for electrcity and natural gas}\end{aligned} \tag{3}$$

[3] Based on data from Bank of Canada and Innovation Science and Economic Development Canada (Innovation Science and Economic Development Canada, 2014; Bank of Canada (2016)).

Table 8
Annual recurring energy costs at household level.

Dwelling type			SFA	SFD	SCC
Scenario 1					
Total energy cost (CA$/HH/a)	Heat	Natural Gas	521	765	371
	Electricity	Electricity	564	805	416
Scenario 1 - Total			1085	1570	788
Scenario 2					
RE cost (CA$/HH/a)	Heat	N/A	0	0	0
	Electricity	Rooftop PV	55	109	0
		Centralised PV	16	18	9
Conventional fuel cost (CA$/HH/a)	Heat	Natural Gas	521	765	371
	Electricity	Electricity	250	244	373
Scenario 2 - Total			841	1137	754
Scenario 3					
RE cost (CA$/HH/a)	Heat	Geothermal	142	142	142
	Electricity	Rooftop PV	55	109	0
		Centralised PV	16	18	9
Conventional fuel cost (CA$/HH/a)	Heat	Natural Gas	294	391	234
	Electricity	Electricity	250	244	373
Scenario 3 - Total			756	905	758
Scenario 4					
RE cost (CA$/HH/a)	Heat	Geothermal	142	142	142
	Electricity	Rooftop PV	55	109	0
		Centralised PV	16	18	9
		MSW plant	116	132	64
Conventional fuel cost (CA$/HH/a)	Heat	Natural Gas	294	391	234
	Electricity	Electricity	32	51	323
Scenario 4 - Total			655	844	771

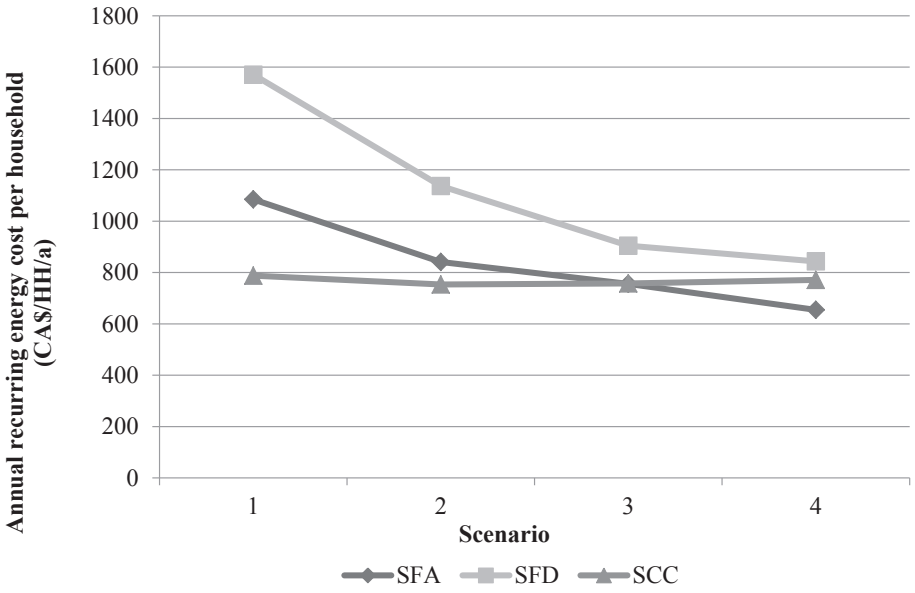

Fig. 5. Annual recurring energy costs at household level.

Table 9 provides details on community level annual expenditure on alternative energy scenarios, and the emissions reduction achieved by the investment made under each scenario. The annual capital cost was calculated based on the annualised LCC of investment for RE facilities. The highest emissions reduction per dollar invested is obtained through scenario 3. While an additional investment is required for the MSW-to-energy system, it does not result in a corresponding reduction in emissions.

In selecting the best scenario-based on an economic perspective, various stakeholders may have differing opinions. Besides the directly perceived outcomes, government also may consider the indirect costs and benefits arising from adoption of the initiatives. The developers may be more interested in going for the lowest cost option, or maybe a compromise which mitigates the economic burden. It is necessary to study the impact on different stakeholder groups to obtain an idea of their acceptance.

3.3. Multi stakeholder benefit/cost

The additional investment requirements for a house of each dwelling type are given in Table 10. The additional investment required per square foot and at a community increases through scenarios 1 to 4.

This information can be used to estimate the additional development costs for the community, and thereby the additional financial burden on home buyers due to the implementation of

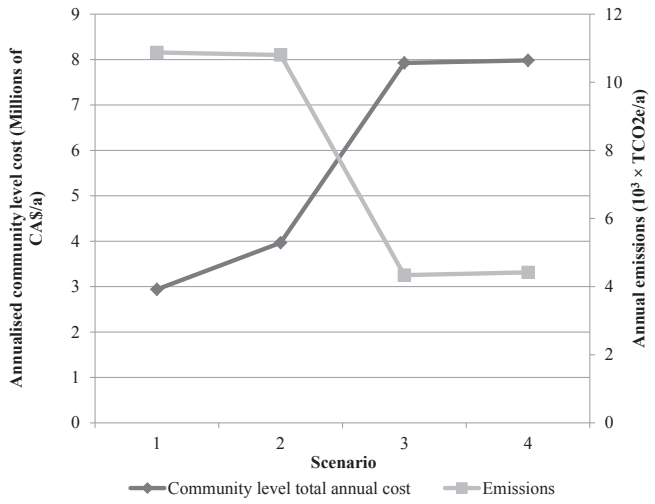

Fig. 6. Community level cost and emissions forecast.

green energy technologies in the community energy system. The additional investment requirement calculated for a square foot of each dwelling type can be used to estimate the cost variations for housing of similar type with different floor area. For a developer, the per square foot investment requirement can also be used to assess the funding requirement with variations in size and composition of the community. The extra costs will be incurred by the developer at the community development stage. The additional costs may be passed onto home buyers as premiums when the developed residences are being sold. Table 11 details the percentage increase in home prices due to the additional investment made on alternative energy options. This information can be compared with green housing premiums to evaluate the acceptability of the interventions to the stakeholders based on a financial perspective.

The saving in recurring expenditure on energy has been tabulated under each scenario for a 25-year lifespan in Table 12. This is the economic benefit to the homeowners in terms of energy cost savings during their occupancy. However, the lifetime reduction in recurring costs does not match with the additional investment requirements, and thereby the increase in home prices. Therefore, in a purely financial sense, the additional investment may not payoff for the homeowners.

At the government level, the stakeholder interest is mainly focused on the possible emissions reduction. Table 13 details the potential emissions reductions which can be achieved in each province in a similar newly developed community under the proposed scenarios. The grid electricity emissions factor for BC was obtained from the "2014 BCE Best Practices Methodology for Quantifying GHG Emissions" published by the BC Ministry of Environment (BC Ministry of Environment (2014)), while the emissions factors for other provinces were adapted from the "National Emissions Inventory" data submitted by Canada to the United Nations Framework Convention on Climate Change (Environment and Climate Change Canada, 2016). As the emissions factor for the provincial grid electricity varies depending on the energy source mix used in electricity generation, the environmental benefit which can be obtained through moving to renewable electricity sources also changes.

Provinces with a higher emission factor for their grid electricity can achieve better results in terms of emissions reduction by incorporating renewable sources such as solar PV in their electricity mix. Fig. 7 compares the emissions reduction trend predicted for the newly developed community in BC under the scenarios, against the potential emissions which can be predicted if the same community were located in Alberta, Nova Scotia or Quebec. An interesting observation is that while the overall emissions increase with the incorporation of the MSW-to-electricity option in BC and Ontario, (which have lower emissions factors), it leads to a decrease in net emissions for Alberta and Nova Scotia.

4. Discussion

Federal Sustainable Development Strategy (FSDS) of Canada from (2013–2016) includes mitigating climate change and air quality; sustaining water quality and availability; protecting nature and Canadians and lowering the environmental footprint (Canada, 2010). The challenge is how to make policy decisions to support economic competitiveness while applying innovative technologies to increase the use of renewable and clean energy resources, reduce GHG emissions, and use less water in energy production.

Energy use should be an integral consideration of urban design. This research proposed a renewable energy planning framework for urban neighbourhood development. A case study was conducted for an upcoming urban community in Okanagan, BC,

Table 9
Community level investment and emissions reduction.

Scenario	O&M cost (CA$/a)	Capital cost (CA$/a)	Emissions ($kgCO_2e/a$)	Emissions reduction ($kgCO_2e/a$)	Reduction per dollar spent ($kgCO_2e/CA$)
1	0	0	10875637	0	0.00
2	161993	1585383	10801737	73901	0.04
3	571506	5734546	4336789	6538848	1.04
4	1032337	7582616	4420272	6455365	0.75

Table 10
Additional investment requirement.

Scenario	Additional investment per HH (CA$/HH)			Additional investment for the community (CA$)	Additional investment per square foot of floor area (CA$/sq.ft.)			
	SFA	SFD	SCC		SFA	SFD	SCC	Overall community
1	0	0	0	0	0.00	0.00	0.00	0.00
2	12181	22593	1128	27,606,501	6.13	10.00	1.03	5.40
3	37181	47593	26128	99,856,501	18.70	21.07	23.88	19.55
4	38962	49616	27107	104,430,707	19.60	21.96	24.78	20.44

Table 11
Percentage increase in housing prices due to RE interventions.

Dwelling type	Price[a] (CA$/HH)	Percentage increase in home prices			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
SFA	389,030	0.00%	3.13%	9.56%	10.02%
SFD	572,260	0.00%	3.95%	8.32%	8.67%
SCC	292,050	0.00%	0.39%	8.95%	9.28%

[a] The home prices in Table 9 were obtained based on the data published for Central Okanagan by Okanagan Mainline Real Estate Board in 2016 (Okanagan Mainline Real Estate Board, 2016).

Table 12
Lifetime reduction in recurring costs.

Scenario	Reduction in recurring costs (CA$/HH)		
	SFA	SFD	SCC
Scenario 1	0	0	0
Scenario 2	4242	7553	594
Scenario 3	5734	11597	522
Scenario 4	7492	12657	286

Canada. Three renewable energy integration scenarios were compared considering GHG emission reduction and economic impacts. Benefits and cost to key stakeholder groups were compared for each renewable energy integration scenario.

Presently renewable energy sources are integrated into community energy systems on ad hoc basis. The framework proposed in this research is a systematic approach for integrating renewable energy to energy systems of upcoming neighbourhoods. Moreover, this approach would indicate the optimal investment point for the developers, saving costs and time in planning. Here, a scenario-based analysis is conducted to evaluate the potential impacts of integrating renewable energies into the energy system of the community.

4.1. Emissions reduction through renewable energy use

General presumption of renewable energy use is that increase in RE related investments would decrease GHG emissions. Annualised LCC increased from scenario 1 to 4, as depicted in Fig. 6. Although annual GHG emissions decreased from scenario 1–3 from the previous scenario, it slightly increased in scenario 4. Highest GHG emission reduction is achieved in scenario 3. Similarly, in the community context scenario 3 achieved the highest GHG emission reduction per CA$. The increase in emissions between scenarios 3 and 4 could be due to the incorporation of MSW electricity generation to the community energy mix. While MSW and other biomass resources can be categorized as renewable energy sources (Natural Resources Canada, 2015), they are also emissions producers, although with lower impacts compared to conventional fossil fuels (Laryea-Goldsmith et al., 2011). However, the use of MSW in electricity generation can also act as a sustainable waste management strategy, providing a solution to the growing issue of urban waste (Laryea-Goldsmith et al., 2011). Therefore, additional social and indirect economic benefits may act as incentives in adopting this technology option.

In Canada provincial grid electricity mix varies. This study used the BC electricity generation mix for the grid electricity. The results of this study may change if the grid electricity mixes changes. Therefore, a detailed study considering regional constraints is needed in this research. In Fig. 4, it can be noted that the reduction in emissions is not significant between scenarios 1 and 2, where solar PV generated electricity partly replaces conventional grid electricity. A possible reason for this finding could be the energy mix in the BC grid, where around 90% of the electricity is produced through hydroelectric generation which is a clean resource with negligible emissions and relatively low costs (BC Hydro, 2016). This situation could potentially change in a province with a higher contribution to electricity generation through fossil fuels, such as Alberta, where around 90% of the electricity is produced through coal and natural gas (Alberta Energy, 2015). With the information provided in Table 13 and Fig. 7, it can be seen that the suitability of various sources in a community energy mix varies by province, based on the characteristics of the current resources. Another hypothesis which can be made is that while using natural gas in heating is expected to be economically beneficial (FortisBC, 2016a), for provinces with a higher share of hydropower in its grid mix, electric heating may be more advantageous especially when the environmental aspect is considered. While biomass-based electricity generation does not appear to deliver significant benefits in terms of emissions reduction in provinces such as BC, it is estimated to result in considerable emissions reduction in provinces with higher emissions factors for grid electricity (i.e. Alberta). This further provides evidence that MSW can be considered a cleaner energy source in comparison to coal and natural gas.

Table 13
Potential emissions reduction trends by province under proposed scenarios.

Province	Grid electricity emissions factor ($kgCO_2e/GJ$)	Total emissions of the community						
		Scenario 1	Scenario 2		Scenario 3		Scenario 4	
		Emissions (TCO_2e/a)	Emissions (TCO_2e/a)	% reduction	Emissions (TCO_2e/a)	% reduction	Emissions (TCO_2e/a)	% reduction
British Columbia	2.8	10876	10802	1%	4337	60%	4420	59%
Alberta	252.8	19869	13197	34%	6732	66%	4664	77%
Ontario	13.9	11275	10908	3%	4443	61%	4431	61%
Nova Scotia	200.0	17970	12691	29%	6226	65%	4612	74%
New Brunswick	77.8	13574	11520	15%	5055	63%	4493	67%
Manitoba	1.1	10814	10785	0%	4321	60%	4419	59%
Quebec	0.6	10796	10781	0%	4316	60%	4418	59%
PE Island	77.8	13574	11520	15%	5055	63%	4493	67%
Saskatchewan	222.2	18768	12904	31%	6439	66%	4634	75%
Newfoundland & Labrador	8.6	11084	10857	2%	4392	60%	4426	60%

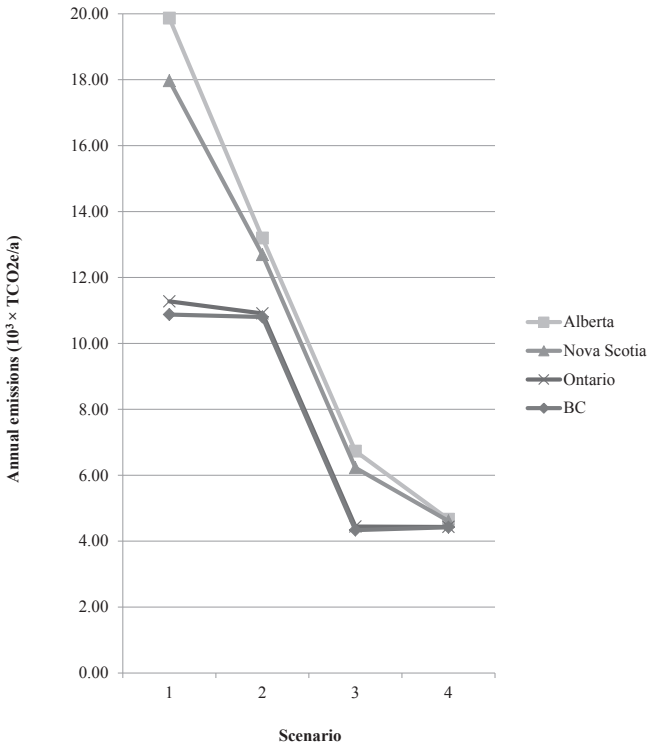

Fig. 7. Emission reduction trends for a community in different provinces.

4.2. Economic considerations for renewable powered communities

Cost is an important factor in devising environmental policies (Cai et al., 2008). Likewise, selection of renewable energy sources can differ according to availability of funding. In most cases, community development companies are not interested in long-term community operations. However, since renewable energy initiatives are installed at the construction phase, developer is compelled to bear this incremental cost. The initial investment for renewable energy scenarios could be as much as $104 million (Scenario 4). Developer could fully or partially recover this investment via premium prices for residential units. Scenario 1 achieves the highest net profit for the developer, as there are no incremental costs. However, the developer would incur a loss in scenario 3 (which achieves the highest GHG emission reduction), if the housing prices are not set to reflect the additional investment made on renewable energy technology implementation.

As a result, options available to the community development company includes, charging premium prices of the houses and establishing or starting a joint venture with an energy utility company for the long-term operation of the community energy system. Studies indicate that homeowners are prepared to pay higher premiums for "green-rated" houses, and a green certification label adds 9% on average to the selling price of housing (Harney, 2012). It can be seen in Table 11 that the increase in home prices after adding the RE interventions in each scenario falls within or close to this range.

However, all potential homeowners may not be willing to pay an additional cost of this nature. The developer operates with a profit motive. Hence, the incremental costs required for the scenarios could be funded in numerous ways. There are schemes such as loans for financing RE initiatives, sale of GHG emissions reduction credits, investment funds from venture capital organisations, and national and international grants for facilitating this (Canadian Renewable Energy Alliance, 2006). Moreover, federal and regional authorities could provide various incentives such as tax breaks, grants and low interest loans to the developers. Aforementioned initiatives would encourage the use of RE in communities, which in turn will increase the environmental performance and energy security.

4.2.1. Funding for renewable energy initiatives

According to community energy and emission inventory of BC, GHG emission from the local municipality is estimated to be 43,213 TCO_2e/a in 2010. The municipality expects to achieve 33% reduction below 2007 levels in GHG emissions by 2020, followed by 80% reduction in 2050 (BC Hydro and Community Energy Association, 2012). Assuming the proposed project is the only future growth, the annual community GHG emission would increase by 4337 TCO_2e/a, if the optimal scenario is selected. Scenarios 1, 2 and 4 would increase GHG emissions of the region by 6539, 6465 and 83 TCO_2e/a respectively over the level predicted by the best scenario. Maximum GHG emission reduction is the desired scenario-based on an environmental perspective, in order to achieve GHG reduction targets of BC. Scenario 4 delivers an emissions reduction of 60% over the business-as-usual case depicted in scenario 1. As such, developer could also partner with the municipality to share the costs required for the optimal scenario. With this type of cost sharing agreement, the economic impact on the developer, and the subsequent passing down of costs to the home buyers will be mitigated.

The cost savings generated through renewable energy alternatives may presently not be justification by themselves in an economic sense for replacing conventional sources. A unit of energy produced through RES may cost higher than one generated through conventional sources. However, with increased penetration of RE, the cost per unit of RE-based energy will reduce, as evidenced by the decline of solar PV panel pricing with increased market share (Poissant et al., 2015). This will lead to future grid parity and greater acceptance of RE at community level. Thus, investing in RE for increased penetration is vital for environmental impact mitigation. Addressing the need for sources of finance, polices promoting investment in RE and financing mechanisms that allow developers to pay back loans or investors at lower rates will further facilitate the penetration of RE based community energy systems (Canadian Renewable Energy Alliance, 2006). Depending on the emissions reduction policies of the local governments, funding and providing other financial incentives to promote this type of venture can aid the achievement of regional environmental goals.

4.3. Further work and limitations

Scenario 4 is the best scenario from the future residents' perspective, in reducing the communities' energy costs. However, this in turn is coupled with an increase in the initial investment of the community, and therefore home prices. The community energy performance is associated not only with energy planning but proper design, construction and informed behavioral patterns. Public Works and Government Services Canada (2001) stated the importance of using a systems approach into building design and occupancy which can minimize the energy use within the building and residential unit. However, improved efficiency can be counterbalanced by increased consumption (Ryan and Campbell, 2012). Therefore, in order to improve energy performance of a community long-term energy plans should consider energy conservation (i.e. reduction of energy demand by changing behavioral patterns of the occupants and use of innovative technologies (Metz et al., 2007)), energy saving (i.e. using materials and products that are not energy consuming, but eventually help to reduce the energy use within a building (Metz et al., 2007)) and energy efficiency (i.e. use of novel

technologies that allow continuing same behavioral patterns with less energy consumption (Denis and Parker, 2009). Aforementioned approaches should be given proper consideration in formulating a sustainable long-term community energy plan.

In this analysis, it can be identified that developing an optimal community energy plan is dependent on multiple conflicting objectives in terms of capital costs, energy savings and environmental impacts. The social acceptability of proposed interventions depend on how these factors are managed and balanced in the energy plan.

Several limitations are associated with this study. The study was developed based on the data from the initial development plan of the community development project considered. Though the project considered was a sequential process from 2015 to 2040, the neighbourhood was assumed to be completed overnight, with effect from 2016. Moreover, Canadian average values were used for residential energy intensities and end use shares. However, additional amenities may be incorporated into the project. Moreover, life patterns of the residents can differ from the average Therefore, the actual energy demand in the community may differ from the calculated values. Furthermore, this research did not consider the uncertainty associated with the parameters.

The costs and the energy generation due to the centralised solar PV and MSW plants were allocated to the households on the basis of square footage. However, this basis of allocation might introduce a bias in the analysis, as the energy intensity of the dwellings does not necessarily reflect the variation in floor area due to the different occupancy patterns of the residents. This is especially true in the case of senior congregate care type dwellings.

The emissions analysis in this study was conducted using only the operational emissions of the selected technologies. However, in order to assess the full environmental impact of integrating such energy scenarios, a life cycle impact assessment needs to be carried out for each option. While long-term energy research mainly focuses on the global warming potential (i.e. GHG emissions) and economic aspects (Prakash and Bhat, 2009; Bhat and Prakash, 2009), there are many other life cycle environmental factors and consequences related to renewable energy use (e.g. in construction of facilities) (Environment Canada, 2010). Life cycle assessment (LCA) can be used to evaluate the environmental impacts of a technology from the source material production to the disposal (Hong et al., 2014). The hidden environmental impacts associated with any “clean” technology can only be identified through a LCA based approach.

This study unfolds several research streams. The proposed framework uses a scenario-based approach for renewable energy planning. An optimization based approach could gain an optimal solution for renewable energy integration plans. With the multiple conflicting objectives of costs, energy savings and environmental impacts, this leads to a multi-criteria decision making problem. Further research is required to assess costs and benefits of an optimization based approach. Perhaps the same concept could be used to develop a user friendly software, which could integrate technical feasibility, regional constraints and stakeholder requirements into the model. A decision support tool which can be used in planning community energy systems will be useful for regional decision makers and developers. Urban sprawl creates many social economic and environmental problems. Therefore, future research should extend to other social economic and environmental impacts to achieve the optimal growth strategy.

5. Conclusions

This research proposed a renewable energy planning framework for community development projects. A scenarios based study was conducted for an upcoming neighbourhood in Okanagan, BC, Canada. Multi stakeholder benefits and costs were investigated for various renewable energy integration scenarios. This study would benefit developers in formulating their energy strategy and local governments in planning for reducing their emissions in line with provincial targets. Funding mechanisms are an important consideration affecting the acceptability of RE initiatives. Developers can also recover the incremental cost by charging premium prices for houses and government subsidies.

Detailed energy and emissions planning should be a requirement for the approval process of upcoming neighbourhoods. This approach would close scrutinize RE based emission reduction alternatives from the project design stage, which is the most effective stage for implementation.

Based on this study, it is important to identify the optimal renewable energy investment for neighbourhood plans. An increase in investments does not necessarily gain high GHG emission reduction. The suitability of renewable options depends on the local situation, availability of energy resources and the existing energy mix in a given location. To evaluate the feasibility of emissions reduction and to estimate the potential benefits of RE integration, it is necessary to study the regional energy mix pertaining to the intended site location of a proposed community. The findings of the study indicated that the level of environmental impact reduction achievable through RE integration greatly varies by province in the Canadian context.

Federal government and other regulatory bodies can create a positive effect on community energy performance and associated environmental impacts. A federal renewable energy plan can act as a roadmap for future community development projects. For successful implementation of community level renewable energy plans, a long-term strategy ensuring cooperation with household, local, provincial, and national bodies is necessary.

Acknowledgements

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Appendix A

Centralised solar PV plant

Panel life span	25 years (Hydro, 2016b)
Plant capacity	2 MW
Solar regional factor	1133 kWh/kWp/a (BC HydroFortisBC, 2015)
Inverter efficiency	90%
Annual electricity generation	2039.4 MWh
Plant installation cost	5,265,000 CA$ (National Renewable Energy Laboratory, 2016)
Annual operational and maintenance cost	41,600 CA$ (National Renewable Energy Laboratory, 2016)

Rooftop solar PV system

Panel life span	25 years (Hydro, 2016b)
Panel capacity	4 kW (ref)
Solar regional factor	1133 kWh/kWp/a (BC HydroFortisBC, 2015)
Annual electricity generation	4800 kWh
System installation cost	20,264 CA$ per household (National Renewable Energy Laboratory, 2016)
Annual operational and maintenance cost	109 CA$ per household (National Renewable Energy Laboratory, 2016)

MSW-to-energy plant

Plant capacity	300 kW
Plant life span	25 years (Department for Environment Food and Rural Affairs, 2014)
Annual energy generation	Depends on the population − Per capita annual energy generation 0.3678 MWh
Plant installation cost	4,574,206 CA$ (Hydro, 2013b)
Annual operational and maintenance cost	46 CA$ per capita (Hydro, 2013b)

Geothermal heating system

Annual heat energy supplied	60% of the household heat load
System life span	25 years U.S. Department of Energy (2016)
System installation cost	25,000 CA$ (Canadian GeoExchange Coalition, 2016)
Annual operational and maintenance cost	142 CA$ per household (National Renewable Energy Laboratory, 2016)

Appendix B

Residential electricity rates (FortisBC, 2016b)

Customer charge	31.23 CA$ for 60-day billing cycle
First 1600 kWh	9.845¢ per kWh
Additional consumption	15.198¢ per kWh

Electricity cost per billing cycle per household (if total consumption < 1600 kWh) = (Customer charge) + (0.09845* kilowatt-hours of electricity consumed per cycle).
Electricity cost per billing cycle per household (if total consumption > 1600 kWh) = (Customer charge) + (0.09845* 1600) + (0.15198 * (kilowatt-hours of electricity consumed per cycle − 1600)).

Natural Gas rates (FortisBC, 2016c)

Basic Daily charge	0.389 CA$
Delivery charge (per GJ)	4.018 CA$
Storage and transport charge (per GJ)	0.921 CA$
Cost of gas (per GJ)	1.141 CA$

Annual Natural Gas cost per household = (Basic daily charge*365) + ((Gigajoules of energy supplied through natural gas per year per household) * (Delivery charge + Storage and transportation charge + cost of gas).

Appendix C

Energy source	$kgCO_2e/GJ$
BC grid electricity (BC Ministry of Environment (2014))	2.80
Alberta grid electricity (BC Ministry of Environment (2014))	225
Ontario grid electricity (BC Ministry of Environment (2014))	29
Natural Gas (BC Ministry of Environment (2014))	65.75
Solar PV (Environment Canada, 2012)	0.00
Geothermal (Kagel et al., 2007)	0.00
MSW (World Nuclear Association, 2011)	12.50

Appendix D

Scenarios	Emissions by energy source (TCO_2/a)				
	Natural Gas	Grid Electricity	Solar PV	Geothermal heating	MSW
1	10774.91	100.72	0.00	0.00	0.00
2	10774.91	26.82	0.00	0.00	0.00
3	4309.97	26.82	0.00	0.00	0.00
4	4309.97	2.73	0.00	0.00	107.58

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